**Diffusion!**

Diffusion is a game intended to simulate the diffusion of atoms among lattice sites within two metals as they form an alloy. The goal of the game is to work with your partner to obtain the maximum amount of interdiffusion before 12 rounds are up by moving atoms into open vacancy sites. Diffusion is based on a Monte Carlo simulation of diffusion in two metals, and relies on probability to determine whether or not an atom had the energy to overcome the displacement barrier energy and move into the vacancy. Your success is determined by how many atoms you move onto your partner's side, and by how far they go. The object of the game is to get the highest combined score possible in 24 moves, representing the most diffusion.

**Game board**
- The game board represents a Hexagonal close-packed plane with 40 positions, 20 on each side, 4 close-packed columns on each side of the interface

**Setup**
- Place the turn marker at turn one
- Fill the player one side of the starting area (box on the left side of the board) with Copper atoms
- Fill the other side of the starting area with atoms of a solute element
- One player will be playing as the Copper host while the other player will be playing as the metal Solute.

**Solute Elements**
- Zinc (Zn)
- Tin (Sn)
- Iron (Fe)

Each solute has a different probability of moving into a vacancy depending on what elements are present surrounding it. Iron in particular has a high displacement barrier to overcome, corresponding to a low probability of movement, and will therefore struggle to interdiffuse.

See page 4 for examples

**Vacancy Formation**
1. One player will roll a die to set the temperature gauge and number of vacancies.
2. The temperature gauge affects how many vacancies are present in the sample. A die is rolled to determine what the temperature will be. At higher temperatures the equilibrium concentration of vacancies increases.
   - (1) → 400K, 2 vacancies along interface
   - (2-3) → 500k, 3 vacancies
   - (4-5) → 700k, 4 vacancies
   - (6) → 900k, 5 vacancies
3. Place the temperature marker on the appropriate temperature
4. Starting with the player who did not roll for the temperature, players take turns choosing locations where the vacancies in the material form. Remove those pieces from the board. Forming vacancies around the interface is advised at lower temperatures.

See page 5 for examples
**Gameplay**

The person playing as the host (Copper) moves first

1. Pick a vacancy with at least one of your atoms around it
2. Choose one of your surrounding atoms to move into the vacancy
3. Roll a die to determine if your atom had enough energy to overcome the barrier and move into the vacancy.
   - You must have at least as much energy as is listed on your element card for the number of your atoms surrounding the vacancy in order to move
   - Look up the value of the dice roll, representing the energy barrier which the atom must overcome to move.
   - The value is different based on the local environment the atom is moving into.
     - Two vacancies or more together give a 100% chance of movement for all elements except for Iron, which resists diffusion
     - Moving into a vacancy at the board edge is also a free move. This simulates surface diffusion, which occurs more freely along the exterior of a sample.
4. Increment the turn counter

See pages 6-7 for examples

**Scoring**

- Each piece on the opposing side of the interface at the end of the game is worth 1 point per column towards the opposite end of the board (so a piece at the opposite end of the board is worth 4 points, while a piece just across the interface is worth 1 point, and pieces on their starting side are worth 0 points).

<table>
<thead>
<tr>
<th>Player 1 Column 4</th>
<th>Player 1 Column 3</th>
<th>Player 1 Column 2</th>
<th>Player 1 Column 1</th>
<th>Interface</th>
<th>Player 2 Column 1</th>
<th>Player 2 Column 2</th>
<th>Player 2 Column 3</th>
<th>Player 2 Column 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>16 points</td>
<td>9 points</td>
<td>4 points</td>
<td>1 point</td>
<td>x</td>
<td>1 point</td>
<td>4 points</td>
<td>9 points</td>
<td>16 points</td>
</tr>
</tbody>
</table>

- A high combined score corresponds to more interdiffusion.

See page 8 for examples
Examples
Game board for Diffusion!

<table>
<thead>
<tr>
<th>Turn 1</th>
<th>Turn 2</th>
<th>Turn 3</th>
<th>Turn 4</th>
<th>Turn 5</th>
<th>Turn 6</th>
<th>Turn 7</th>
<th>Turn 8</th>
<th>Turn 9</th>
<th>Turn 10</th>
<th>Turn 11</th>
<th>Turn 12</th>
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<th>Turn 16</th>
<th>Turn 17</th>
<th>Turn 18</th>
<th>Turn 19</th>
<th>Turn 20</th>
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<table>
<thead>
<tr>
<th>Temperature</th>
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</thead>
<tbody>
<tr>
<td>400k</td>
</tr>
<tr>
<td>500k</td>
</tr>
<tr>
<td>700k</td>
</tr>
<tr>
<td>900k</td>
</tr>
</tbody>
</table>

Turn Counter
Temperature Gauge
Host starting area
Solute starting area
Player one start
Player two start
Interface (middle of board)
Setup

Below you will find an example of a game of set up and sample turns of a game of Diffusion between Copper and Tin. The game in question is played at 500k between two players, who are working together to attempt to get the maximum number of points as a team.
**Vacancy Creation**

Player two then roles to determine the temperature at which the game will be played, which determines the number of vacancies that will be formed. In our example a 3 has been rolled, setting the temperature to 500k.

In this case the person playing as copper has removed an atom from their side forming a vacancy, followed by the tin player removing an atom from their side, after which the copper player created the final vacancy by removing an atom from their side.
**Movement**

It is now the first turn, and copper has selected the vacancy in the first row of tins side to move into, and has selected the atom shown by the arrow to move into the vacancy. Because there are two copper atoms present around the vacancy, player one must roll a 4 or higher for the copper atom to have enough energy to move into the vacancy.
Lets take a look at the board after a few successful moves by the players and a few moves where the atoms did not have enough energy to overcome the displacement barrier energy.

We can see that the players are starting to achieve some diffusion between the two sides, and that the turn counter has been incremented each time they attempted a move. Copper was a strategic player and made room for tin on his side by moving copper atoms on his own side to shift vacancies where they would help tin diffuse.
**Scoring**

Now let's take a look at scoring Diffusion! In the image below the players have completed their game after 24 turns, and are now attempting to score their moves.

In this game, Player one earned 1 point each for the copper atoms in the first column of Player two’s side, and 4 points for the atom in column two of Player two’s side. Player two has earned 1 point each for the two atoms of tin on column 1 of Player one’s side and 9 points for the atom of Tin in column 3 of Player one’s side. This resulted in a combined score of 17 points for the two players, or 6 points for player one and 11 points for player 2.